APPENDIX J:

ENVIRONMENTAL IMPACTS OF TRANSPORTATION OF UF_6 CYLINDERS, URANIUM OXIDE, URANIUM METAL, AND ASSOCIATED MATERIALS

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The following is a list of acronyms and abbreviations, including units of measure, used in this document. Some acronyms used only in tables are defined in those tables.

ACRONYMS AND ABBREVIATIONS

General

CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
ICRP	International Commission on Radiological Protection
LCF	latent cancer fatality
LLNL	Lawrence Livermore National Laboratory
LLMW	low-level mixed waste
LLW	low-level radioactive waste
MEI	maximally exposed individual
NEPA	*National Environmental Policy Act*
PEIS	programmatic environmental impact statement

Chemicals

CaF_2	calcium fluoride
HF	hydrogen fluoride; hydrofluoric acid
MgF_2	magnesium fluoride
NH_3	ammonia
UF_6	uranium hexafluoride
UO_2	uranium dioxide
U_3O_8	triuranium octaoxide (uranyl uranate)

UNITS OF MEASURE

ft	foot (feet)
h	hour(s)
kg	kilogram(s)
km	kilometer(s)
lb	pound(s)
m	meter(s)
mrem	millirem(s)

APPENDIX J:

ENVIRONMENTAL IMPACTS OF TRANSPORTATION OF UF_6 CYLINDERS, URANIUM OXIDE, URANIUM METAL, AND ASSOCIATED MATERIALS

The U.S. Department of Energy (DOE) is proposing to develop a strategy for long-term management of the depleted uranium hexafluoride (UF_6) inventory currently stored at three DOE sites in Paducah, Kentucky; Portsmouth, Ohio; and Oak Ridge, Tennessee. This programmatic environmental impact statement (PEIS) describes alternative strategies that could be used for the long-term management of this material and analyzes the potential environmental consequences of implementing each strategy for the period from 1999 through 2039. This appendix provides detailed information describing the transportation of radioactive and other hazardous materials associated with the options considered in the PEIS. The discussion provides background information, as well as a summary of the estimated environmental impacts associated with transportation.

> **Transportation**
>
> The transportation of hazardous and radioactive materials was assessed for all alternative strategies considered in the PEIS for management of the depleted UF_6 inventory currently stored at three DOE sites. For purposes of analysis, it was assumed that all long-term storage, conversion, disposal, and manufacture and use facilities would be located at different sites, thus requiring the transportation of materials between sites. The PEIS transportation assessment considered the impacts from all shipments associated with each category of the options that make up the alternatives. The materials considered include depleted UF_6 cylinders, uranium conversion products, chemicals required for or produced during processing (such as hydrogen fluoride and hydrochloric acid), as well as any low-level radioactive, low-level mixed radioactive, and hazardous waste generated during operations. The analysis considered both truck and rail shipment options.

All of the PEIS alternatives would involve some transportation of radioactive and hazardous materials. For purposes of the PEIS analysis, it was assumed that all long-term storage, conversion, disposal, and manufacture and use facilities would be located at different locations. Thus, transportation would form the links between the options that make up each of the PEIS alternatives, as shown graphically in Chapter 2, Figures 2.2 through 2.6. In reality, the transportation activities actually required by an alternative would depend on the locations of the facilities involved — if facilities were colocated, the transportation of materials, and any associated impacts, would be minimized or eliminated.

The transportation assessment considered all shipments associated with the categories of options that make up each of the PEIS alternatives. The primary uranium materials transported under these alternatives include depleted UF_6 cylinders, uranium oxide (uranium dioxide [UO_2] or triuranium octaoxide [U_3O_8]), uranium metal, and uranium oxide and uranium metal storage casks (see Table J.1). Also, each alternative would involve transportation of chemicals required for or

TABLE J.1 Primary Uranium Materials Transported under Each Management Alternative

	Primary Material Transported[a]				
PEIS Alternative	Depleted UF_6 Cylinders	Oxide (UO_2 or U_3O_8)	Uranium Metal	Uranium Oxide Casks	Uranium Metal Casks
No action	–	–	–	–	–
Long-term storage as UF_6	X[b]	–	–	–	–
Long-term storage as oxide	X	X	–	–	–
Use as uranium oxide	X	X	–	X	–
Use as uranium metal	X	–	X	–	X
Disposal	X	X	–	–	–

[a] In addition to the uranium materials listed, each alternative would also involve the transportation of chemicals required for or produced during processing, as well as LLW and LLMW.

[b] X indicates that the material was assumed to be transported under that PEIS alternative.

produced during processing (such as hydrogen fluoride [HF]), as well as any low-level radioactive waste (LLW), low-level mixed waste (LLMW), and hazardous chemical waste generated during operations.

Impacts from the on-site transportation of the various materials at the different facilities (conversion, storage, manufacture, and disposal) were not computed. On-site transportation impacts are expected to be negligible when compared with the impacts associated with the off-site transportation between facilities. On-site shipments of over 19 miles (30 km) were assessed for the Hanford site for comparison with off-site shipments analyzed in the *Waste Management Programmatic Environmental Impact Statement* (DOE 1997). The on-site impacts were found to be more than 100 times smaller than the off-site impacts, primarily because of the much shorter shipment distances involved (Biwer et al. 1996). For the depleted UF_6 PEIS, shorter on-site distances are likely; therefore, the on-site transportation impacts are also expected to be more than 100 times smaller than the off-site impacts. The decisions to be made based on this PEIS would not be affected by on-site transportation impacts. In addition, transportation impacts would be much smaller for on-site shipments than off-site shipments and would also be smaller than the impacts associated with loading and unloading shipments for off-site shipments, which were included in the involved worker doses estimated for facility operations.

Additional details regarding the methodology used to assess transportation impacts are provided in Biwer et al. (1997).

J.1 SUMMARY OF TRANSPORTATION OPTION IMPACTS

The potential environmental impacts associated with transportation activities for the PEIS alternatives are summarized in Table J.2. For purposes of comparison in Table J.2, the analysis was based on the assumption that all shipments would be transported a distance of 620 miles (1,000 km), regardless of the type of material. (Transportation impacts were evaluated for distances ranging from 155 to 3,100 mi [250 to 5,000 km] in Section J.3.) The assessment considered impacts on human health that would result from the radioactive and hazardous chemical characteristics of the materials shipped, as well as the impacts that would result from operation of the transportation vehicles. Additional discussion and details related to the results for individual areas of impact are provided in Section J.3.

Various options were considered for each alternative, including the following transportation-related steps:

- ***No Action Alternative.*** No off-site transportation is expected under the no action alternative, except for a few LLW and LLMW shipments. Minor amounts of LLW and LLMW may be generated during monitoring and maintenance activities associated with the storage of the depleted UF_6 cylinders at their current locations. Fewer than one shipment per year to a disposal site would be expected for the waste generated, and no fatalities would be anticipated from waste shipments. Shipment impacts are expected to be negligible, similar to LLW and LLMW shipments from the cylinder treatment facility or the cylinder transfer facility as considered under other alternatives.

- ***Long-Term Storage as UF_6.*** Long-term storage as UF_6 would involve transportation of the depleted UF_6 cylinders from the three existing storage sites to a long-term storage facility. The cylinders might be shipped in overcontainers. If a transfer facility were used to alleviate the problem of substandard cylinders before shipment of the UF_6, shipment of LLW and LLMW from the transfer facility would be required.

- ***Long-Term Storage as Oxide.*** Long-term storage as oxide (UO_2 or U_3O_8) would involve transportation of the depleted UF_6 cylinders to an oxide conversion plant. The conversion facility would also require inbound shipments of ammonia and outbound shipments of HF and waste. Cleaning of the empty cylinders at a cylinder treatment facility colocated with the conversion facility would require outbound shipments of U_3O_8 and waste. The final transportation step would be shipment of the oxide to the long-term storage facility.

TABLE J.2 Summary of Transportation Impacts by Alternative[a]

Impacts from Long-Term Storage as UF_6	Impacts from Long-Term Storage as Oxide	Impacts from Use as Uranium Oxide Cask	Impacts from Use as Uranium Metal Cask	Impacts from Disposal
Total Shipments: LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666	**Total Shipments:** LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666 HF: 0 – 4,860 NH_3: 0 – 1,120 LLW (oxide conversion): 320 – 1,680 LLMW (oxide conversion): 20 – 40 CaF_2: 180 – 19,760 Oxide: 8,480 – 26,800	**Total Shipments:** LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666 HF: 0 – 4,860 NH_3: 0 – 1,120 LLW (UO_2 conversion): 360 – 1,680 LLMW (UO_2 conversion): 20 – 40 CaF_2: 180 – 19,760 Oxide: 8,480 – 26,800 LLW (cask manufacture): 300 LLMW (cask manufacture): 20 Uranium oxide casks: 9,600	**Total Shipments:** LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666 HF: 1,640 NH_3: 920 LLW (metal conversion): 360 – 3,840 LLMW (metal conversion): 20 MgF_2: 3,800 – 10,780 Metal: 7,360 – 21,500 LLW (cask manufacture): 1,540 LLMW (cask manufacture): 20 Uranium metal casks: 9,060	**Total Shipments:** LLW (cylinder transfer): 460 – 580 LLMW (cylinder transfer): 60 Cylinders: 11,606 – 46,666 HF: 0 – 4,860 NH_3: 0 – 1,120 LLW (oxide conversion): 320 – 1,680 LLMW (oxide conversion): 20 – 40 CaF_2: 180 – 19,760 Oxide: 8,480 – 26,800
Human Health – Normal Operations: Radiological[b]				
Workers and Public: Total number of LCFs: 0.1 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$	**Workers and Public:** Total number of LCFs: 0.1 – 0.3 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$	**Workers and Public:** Total number of LCFs: 0.1 – 0.3 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$	**Workers and Public:** Total number of LCFs: 0.1 – 0.2 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$	**Workers and Public:** Total number of LCFs: 0.1 – 0.3 Maximum risk of LCF to MEI member of general public (resident along route): $9 \times 10^{-15} - 8 \times 10^{-12}$
Human Health – Normal Operations: Chemical				
Workers and Public: Fatalities from vehicle exhaust emissions: 0.04 – 0.2	**Workers and Public:** Fatalities from vehicle exhaust emissions: 0.08 – 0.4	**Workers and Public:** Fatalities from vehicle exhaust emissions: 0.1 – 0.5	**Workers and Public:** Fatalities from vehicle exhaust emissions: 0.08 – 0.4	**Workers and Public:** Fatalities from vehicle exhaust emissions: 0.08 – 0.4

TABLE J.2 (Cont.)

Impacts from Long-Term Storage as UF_6	Impacts from Long-Term Storage as Oxide	Impacts from Use as Uranium Oxide Cask	Impacts from Use as Uranium Metal Cask	Impacts from Disposal
		Human Health – Accidents: Radiological[b]		
Overall accident risk (LCFs): 0.00007 – 0.0005	Overall accident risk (LCFs): 0.001 – 0.007	Overall accident risk (LCFs): 0.001 – 0.007	Overall accident risk (LCFs): 0.00007 – 0.0005	Overall accident risk (LCFs): 0.001 – 0.007
Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: UF_6 cylinder rail accident in urban area
Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km
Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs	Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs	Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs	Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs	Bounding accident consequences to population within 50 miles (per occurrence): 60 LCFs
Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002	Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002	Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002	Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002	Bounding accident consequences to MEI (per occurrence): Risk of LCF: 0.002

TABLE J.2 (Cont.)

Impacts from Long-Term Storage as UF_6	Impacts from Long-Term Storage as Oxide	Impacts from Use as Uranium Oxide Cask	Impacts from Use as Uranium Metal Cask	Impacts from Disposal
		Human Health – Accidents: Chemical		
Overall accident risk (irreversible adverse effects): 1×10^{-6} – 0.00003	Overall accident risk (irreversible adverse effects): 0.5 – 20	Overall accident risk (irreversible adverse effects): 0.5 – 20	Overall accident risk (irreversible adverse effects): 7	Overall accident risk (irreversible adverse effects): 0.5 – 20
Bounding accident: UF_6 cylinder rail accident in urban area	Bounding accident: HF rail accident in urban area	Bounding accident: HF rail accident in urban area	Bounding accident: HF rail accident in urban area	Bounding accident: HF rail accident in urban area
Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-9} per railcar-km	Bounding accident frequency: 1×10^{-90} per railcar-km
Bounding accident consequences to population within 50 miles (per occurrence): up to 4 irreversible adverse effects	Bounding accident consequences to population within 50 miles (per occurrence): up to 30,000 irreversible adverse effects	Bounding accident consequences to population within 50 miles (per occurrence): up to 30,000 irreversible adverse effects	Bounding accident consequences to population within 50 miles (per occurrence): up to 30,000 irreversible adverse effects	Bounding accident consequences to population within 50 miles (per occurrence): up to 30,000 irreversible adverse effects
Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects	Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects	Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects	Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects	Bounding accident consequences to MEI (per occurrence): expected irreversible adverse effects
		Human Health — Accidents: Physical Hazards		
Total traffic fatalities: 0.6 – 2	Total traffic fatalities: 1 – 4	Total traffic fatalities: 2 – 4	Total traffic fatalities: 1 – 3	Total traffic fatalities: 1 – 4

[a] Shipping distance of 621 miles (1,000 km) for all materials; vehicle-related impacts were based on round-trip distance. The no action alternative is not included in this table (see Table J.1). Fewer than one off-site shipment per year to a disposal site would be expected for the minor amounts of LLW and LLMW generated during monitoring and maintenance activities under this alternative.

[b] Radiological LCFs were estimated from the calculated dose using dose-to-risk conversion factors of 0.0005 and 0.0004 fatalities per person-rem for members of the general public and occupational workers, respectively, as recommended in Publication 60 of the International Commission on Radiological Protection (ICRP 1991). The approximate corresponding dose for each of the radiological fatality risks listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

Notation: CaF_2 = calcium fluoride; HF = hydrogen fluoride; LCF = latent cancer fatality; LLW = low-level radioactive waste; LLMW = low-level mixed waste; MEI = maximally exposed individual; MgF_2 = magnesium fluoride; NH_3 = ammonia; UF_6 = uranium hexafluoride; UO_2 = uranium dioxide.

- ***Use as Uranium Oxide Casks.*** Use as uranium oxide casks would involve transportation of the depleted UF_6 cylinders to a UO_2 conversion plant. The conversion facility would also require inbound shipments of ammonia and outbound shipments of HF and waste. Cleaning of the empty cylinders at a cylinder treatment facility colocated with the conversion facility would require outbound shipments of U_3O_8 and waste. The UO_2 would be transported to a cask manufacturing facility, which would also generate some waste for shipment to disposal. Finally, the casks would be shipped to an end user.

- ***Use as Uranium Metal Casks.*** Use as uranium metal casks would involve transportation of the depleted UF_6 cylinders to a metal conversion plant. The conversion facility would also require inbound shipments of ammonia and outbound shipments of HF and waste. Cleaning of the empty cylinders at a cylinder treatment facility colocated with the conversion facility would require outbound shipments of U_3O_8 and waste. The metal would be transported to a cask manufacturing facility, which would also generate some waste for shipment to disposal. Finally, the casks would be shipped to an end user.

- ***Disposal.*** The disposal option would involve the same transportation steps required for long-term storage as oxide, except that the final shipments of oxide would be sent to a disposal facility rather than a storage facility.

The transportation impacts in Table J.2 are presented as ranges of values. The ranges reflect differences in risk between truck and rail modes and differences in the types and quantities of materials required within a given option. The following is a general summary of potential impacts from transportation activities (based on information in Table J.2 and additional detailed information in Section J.3):

- The analysis of transportation risks presented in Table J.2 was based on the assumption that all shipments would travel a distance of 620 miles (1,000 km) and that essentially the entire inventory of DOE-generated depleted uranium would be shipped between long-term storage, conversion, manufacture and use, and disposal facilities. Transportation risks would be reduced or eliminated by colocating facilities or minimizing shipment distances between facilities.

- In general, the greatest risk from transportation would result from vehicle-related physical hazards, that is, potential fatalities caused by the physical trauma received during transportation accidents, independent of the material transported. This risk would increase directly with the number of shipments and shipment distance.

- The overall transportation risk resulting from the radioactive characteristics of the transported material would be small, generally less than one-tenth of the risk from vehicle-related causes for a given shipment.

- The overall transportation risk resulting from the hazardous chemical characteristics of the transported material would also be small, generally less than one-tenth of the risk from vehicle-related causes for most shipments.

- There is potential for low-probability, severe transportation accidents that could have large consequences. The accidents with the largest potential consequences would be rail accidents involving a tank car containing HF. Under unfavorable weather conditions, the HF released from these accidents could result in approximately 10 irreversible adverse effects in a rural environment or approximately 30,000 irreversible adverse effects in an urban environment. These impacts are discussed in Section J.3.4.2.

- Within each material category, the total transportation risk would be dominated by shipments of depleted UF_6 cylinders, U_3O_8, UO_2, uranium metal, and uranium oxide and uranium metal casks because of the large number of shipments required for these materials. Shipments of waste and process chemicals would not contribute significantly to the overall risk, except for potential shipments of the ammonia required for some conversion options and the HF by-product associated with some conversion options.

- In general, rail transportation would result in a slightly lower overall risk than truck transportation for the same amount of material, due primarily to higher rail shipment capacities and therefore fewer shipments.

J.2 TRANSPORTATION MODES

This assessment of transportation impacts was based on data provided in the engineering analysis report (Lawrence Livermore National Laboratory [LLNL 1997]). For each category of option assessed in the PEIS, the engineering analysis report provides estimates of the types, characteristics, and quantities of each material that would require transportation.

J.2.1 Truck Transportation

Truck transportation was considered for all materials shipped, except for some bulk shipments of HF, ammonia, and spent nuclear fuel casks (which are too large for road transport). Truck shipments would generally be in legal-weight semitrailer trucks, consistent with current practices. The maximum gross vehicle weight for truck shipments is limited by the U.S. Department of

Transportation (DOT) to 80,000 lb (36,400 kg). Truck shipments of depleted UF_6 were assumed to consist of a single cylinder per trailer. Shipments of conversion products and waste materials would generally be near the maximum allowed by weight limitations.

J.2.2 Rail Transportation

Rail transportation was considered as an option to truck transportation for the shipment of bulk materials where the amount of material shipped would justify the use of full railcars. These materials would include depleted UF_6 cylinders and conversion products. For rail transportation, the average payload weights for boxcars range from 100,000 to 150,000 lb (45,000 to 68,000 kg). Rail shipments of depleted UF_6 were assumed to consist of four cylinders per railcar, with transport by regular freight train service. In general, rail transportation was not considered for shipments of waste materials and most chemicals generated or used during processing because the annual volumes of these materials would be much less than typical railcar capacities.

J.2.3 Transportation Options Considered But Not Analyzed in Detail

Air and barge transportation options were considered but not analyzed in detail. Air transportation would be prohibitively expensive and is not practical for shipping waste and large amounts of material. The use of barge transportation for the depleted UF_6 cylinders, conversion products, or manufactured products was considered but not examined in detail because sites for the proposed facilities under consideration in the PEIS have not yet been determined. Generic input parameters to estimate the risks associated with barge transport are not as readily applicable as they are for truck or rail transport because of the fixed and limited nature of the inland and coastal waterways.

The use of barge transport for bulk shipments of depleted uranium materials would be a viable alternative if both the shipping and receiving sites were located near the U.S. inland or coastal waterway systems. In general, the risk per shipment would be approximately the same as for a truck or rail (one railcar) shipment, but fewer shipments would be necessary and the costs per ton-mile much lower. The primary risks to workers would occur during loading and unloading operations. Risks to the public could occur in the vicinity of locks when the barges were stopped during their passage through the locks and from accidents that might result in potential releases to the environment. Barge transport of the depleted UF_6 cylinders from the existing storage sites would first require truck or rail transport to the nearest river port, approximately 20 to 25 miles (32 to 40 km) for the Portsmouth and Paducah sites and approximately 1 mile (1.6 km) for the K-25 site.

J.3 IMPACTS OF OPTIONS

The potential environmental impacts associated with transportation activities are summarized in this section. Additional information related to the assessment methodologies for each area of impact is provided in Appendix C.

J.3.1 General Assumptions

The environmental impacts from transportation were evaluated for each category of option (i.e., cylinder preparation, conversion, long-term storage, manufacture and use, and disposal) on the basis of information described in the engineering analysis report (LLNL 1997). The materials transported for each option category are summarized in Table J.3, along with the origin and destination sites for each material and an indication of whether the material poses a radiological, chemical, or vehicle-related risk. The following general assumptions apply to the assessment of impacts:

- Because sites for long-term storage, conversion, disposal, and manufacture and use will not be selected or known until some time in the future, transportation impacts for each material were estimated as the risk per kilometer traveled, using representative national average route statistics. For comparison, total transportation impacts are presented for shipment distances of 155, 620, and 3,100 miles (250, 1,000, and 5,000 km).

- The assessment of total transportation impacts was based on the assumption that the entire inventory of depleted uranium would be shipped between long-term storage, conversion, manufacture and use, and disposal facilities.

- National average accident occurrence rates (accidents per million miles) and fatality rates (accident fatalities per million miles) were used for accident calculations for truck and rail shipments.

- Transportation impacts were estimated for all shipments of depleted UF_6 cylinders, uranium conversion products, chemicals required for or produced during processing (such as HF and ammonia), as well as any LLW and LLMW generated during operations. Some conversion options would produce large quantities of calcium fluoride (CaF_2) or magnesium fluoride (MgF_2). CaF_2 can be used or disposed of as either sanitary waste or LLW, depending on the residual uranium concentration and applicable regulatory release limits at the time of disposal. Similarly, MgF_2 can be disposed of as sanitary waste or LLW.

TABLE J.3 Summary of Materials Transported for Each Transportation Option

		Risk				
Option Category	Material Transported	Radiological	Chemical	Vehicular	Origin Site	Destination Site
Cylinder preparation	LLW	X	X	X	UF_6 current locations	LLW disposal site
	LLMW	X	X	X	UF_6 current locations	LLMW treatment/disposal site
	Hazardous waste	X	X	X	UF_6 current locations	Hazardous waste disposal site
Conversion	Depleted UF_6	X	X	X	Current locations	Conversion site
	LLW	X	X	X	Conversion site	LLW disposal site
	LLMW	X	X	X	Conversion site	LLMW treatment/disposal site
	Hazardous waste	–	X	X	Conversion site	Hazardous waste disposal site
	U_3O_8	X	X	X	Cylinder treatment facility	Storage or disposal site
	LLW	X	X	X	Cylinder treatment facility	LLW disposal site
	LLMW	X	X	X	Cylinder treatment facility	LLMW treatment/disposal
	Hazardous waste	–	X	X	Cylinder treatment facility	Hazardous waste disposal
	HF and NH_3 (various combinations, depending on conversion option)	–	X	X	Chemical manufacturer or conversion site	Conversion or disposal site
	CaF_2	–	–	X	Conversion site	LLW disposal site
	MgF_2	–	–	X	Conversion site	LLW disposal site
Long-term storage	Depleted UF_6	X	X	X	Current locations	Long-term storage site
	UO_2 or U_3O_8	X	X	X	Conversion site	Long-term storage site
Manufacture and use	Uranium metal or UO_2	X	X	X	Conversion site	Manufacturing site
	LLW	X	X	X	Manufacturing site	LLW disposal site
	LLMW	X	X	X	Manufacturing site	LLMW treatment/disposal site
	Uranium oxide or uranium metal casks	X	–	X	Manufacturing site	End user
Disposal	UO_2 or U_3O_8	X	X	X	Conversion or storage site	Disposal site (shallow earthen structure, vault, or mine)

- For the various options, the transportation risk for a number of shipments listed in the engineering analysis report (LLNL 1997) are not included in this PEIS because they would not pose a radiological risk or a chemical fatality risk. Such shipments include chemicals used for processing (hydrochloric acid, sodium hydroxide, and nitric acid) and output hazardous waste for most facilities. The acids would not be in concentrated form, and sodium hydroxide is not an inhalation hazard. Relatively few drums of hazardous waste would be generated with minor amounts per drum, typically less than 1 or 2 kg of hazardous material, some of which would not be an inhalation hazard.

- In general, transportation activities were assumed to take place over a 20-year period, consistent with the operational period of the facilities considered.

J.3.2 Impacts Considered

The transportation of depleted uranium and associated materials would pose potential risks to human health and the environment. These risks would result from both the radioactive and chemical nature of the materials transported, as well as from operation of the transportation vehicles. The potential risks are discussed in this section. Additional details are given in Appendix C. The collective risks are presented in terms of the expected number of fatalities (or potentially life-threatening effects for chemical impacts) among the general public from all shipments for per-shipment distances ranging from 155 to 3,100 miles (250 to 5,000 km). The risks are presented for both truck and rail options, where appropriate.

J.3.2.1 Human Health — Normal Operations

J.3.2.1.1 Radiological Impacts

Radiological risk associated with routine transportation would result from the potential exposure of people to low levels of external radiation near a radioactive shipment. External exposures could occur as shipments moved past members of the public along routes or while the shipment was stopped along the route. No radioactive materials would be released during routine operations. Collective risks were estimated for the transportation crew members and for members of the public living and working along the transportation routes, sharing the routes, and present at stops along the routes.

In addition to assessing the routine collective population risk, risks to the maximally exposed individual (MEI) were estimated for a number of hypothetical exposure scenarios; these risks are listed in Table J.4. The scenarios include exposure of persons living next to a shipment route or being next to a shipment while stopped in traffic. The scenarios were chosen to provide a

TABLE J.4 Definition of Maximally Exposed Individuals for Assessment of Routine Transportation Risk

Maximally Exposed Individual	Assumptions	Distance (m)	Exposure Duration
Inspector (truck and rail)	Federal or state vehicle inspector, not covered by a dosimetry program	3	30 minutes
Resident (truck and rail)	Person living near a site shipment entrance, not protected by shielding	30	Shipments pass at average speed of 24 km/h
Person at traffic obstruction (truck and rail)	Person stopped next to a radioactive material shipment due to traffic or other causes, not protected by shielding	1	30 minutes
Person at truck service station	Worker at a truck stop	20	2 hours
Resident near a rail stop	Resident living near a rail classification yard, not protected by shielding	200	20 hours

range of exposure conditions; they were not intended to be all inclusive. For the transportation-related radiological impacts assessed in this PEIS, all those resulting from external radiation during routine transport would be very small because the highest level of radiation from any one shipment would be less than 1 mrem/h at a distance of 3.3 ft (1 m) from the transport vehicle. This dose rate is more than 10 times less than the regulatory limit of 10 mrem/h at 6.6 ft (2 m) from the transport vehicle, as directed by the DOT (49 *Code of Federal Regulations* [CFR] Part 173) and the U.S. Nuclear Regulatory Commission (10 CFR Part 71).

J.3.2.1.2 Chemical Impacts

The analysis assumed that no leaks would occur in the shipping packages during normal transport. Therefore, no impacts on human health would be related directly to the hazardous nature of chemical shipments during routine operations.

J.3.2.1.3 Vehicle-Related Impacts (Chemical Hazards)

Vehicle-related health risks are independent of the nature of the cargo and would be incurred for similar shipments of any commodity. The routine risks assessed might be caused by potential exposure to increased levels of airborne particulates from vehicular exhaust emissions and from fugitive dust raised from the roadbed by the transport vehicle. The health endpoint assessed was the excess (additional) latent mortality caused by inhalation of these particulates in urban areas where ambient particulate air concentrations already exceed threshold values thought to be necessary before adverse effects are observed. It was assumed that a latent mortality is equivalent to a latent cancer fatality.

J.3.2.2 Human Health — Accident Conditions

J.3.2.2.1 Radiological Impacts

Radiological impacts from transportation-related accidents could result from the potential release and dispersal of radioactive material into the environment during an accident and the subsequent exposure of people through multiple pathways, such as exposure to contaminated soil, inhalation, or ingestion of contaminated food. The radiological impacts are expressed in terms of latent cancer fatalities (LCFs). No acute effects would be expected for the materials relevant to the action under consideration in this PEIS.

The collective accident risks from radiological causes over the life of the project have been estimated for all radioactive material shipments for each option category (see Table J.3 for a list of shipments). The accident risk estimates were based not only on the consequences of potential accidents but also on the probabilities that accidents would occur.

Although the overall radiological accident risk would be small for all shipments, there would be potential for low-probability, severe transportation accidents that could have relatively large consequences. Population and MEI impacts were estimated for such accidents.

J.3.2.2.2 Chemical Impacts

Chemical impacts from transportation-related accidents could result from the potential release and dispersal of hazardous chemicals into the environment during an accident and the subsequent exposure of people through the inhalation pathway. None of the hazardous chemicals involved in the action under consideration are suspected carcinogens, and any acute effects from ingestion or dermal absorption of the contaminants would be expected to be dominated by inhalation effects. The collective accident risks from chemical causes were estimated in the same manner as the radiological risks, taking into account accident probability, the spectrum of accident severities, and accident consequences. The health endpoints presented are potential irreversible adverse effects and expected fatalities, which are discussed in detail in Appendix C and Policastro et al. (1997). Population and MEI consequences from potentially severe accidents are presented.

J.3.2.2.3 Vehicle-Related Impacts (Physical Hazards)

Accident risks from physical hazards are vehicle-related risks that result from the physical trauma created by accidents; such risks are not related to the shipment's cargo. Physical hazard risks represent fatalities from mechanical causes and were determined from fatality rates based on national average statistics maintained by the DOT for truck and rail transportation (Saricks and Kvitek 1994).

J.3.3 Cylinder Preparation Options

Two options were evaluated for preparing nonconforming cylinders for off-site transportation to either a conversion facility or a long-term storage site (see Appendix E). These problem cylinders were classified into three types: (1) overfilled cylinders, (2) overpressurized cylinders, and (3) substandard cylinders. Each of the two cylinder preparation options would prepare all three types of cylinders to meet all DOT requirements for off-site shipment.

J.3.3.1 Cylinder Overcontainers

An overcontainer would be suitable to contain, transport, and store the cylinder contents, regardless of cylinder condition, and could be designed as a pressure vessel enabling liquefaction of the depleted UF_6 for transfer out of the cylinder. Because only minimal cylinder handling operations would be required to load substandard cylinders into an overcontainer, no chemical transportation risks would be associated with this option. Potential risks associated with the transportation of depleted UF_6 cylinders in protective overcontainers are presented in Sections J.3.4.1 and J.3.5.1 for the conversion options and long-term storage options, respectively.

J.3.3.2 Cylinder Transfer Facility

The alternative to placing nonconforming cylinders into overcontainers would be to transfer the depleted UF_6 to new cylinders. A facility necessary to effect such a transfer was assumed to be colocated at each of the three existing sites where the cylinders are currently stored. Therefore, the only transportation risks would be from minor amounts of chemicals used at the facility and small amounts of LLW and LLMW generated at the facility.

The total collective radiological risks (i.e., the total risk to all workers and members of the general public potentially exposed) for shipments associated with the cylinder transfer option are summarized in Tables J.5 and J.6 for routine and accident risks, respectively. Routine risks to MEIs are summarized in Table J.7, whereas potential severe accident consequences to local populations from radiological and chemical hazards are summarized in Tables J.8 and J.9, respectively. Accident consequences to MEIs are summarized in Table J.10.

TABLE J.5 Total Routine Shipment Risks for the Transportation of Materials for the Cylinder Preparation and Conversion Options

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
Cylinder transfer facility											
LLW	Truck	460 – 580	0.00004 – 0.00005	0	0.0005 – 0.0007	0.0001 – 0.0002	0	0.002 – 0.003	0.0007 – 0.0009	0	0.01
LLMW	Truck	20	2×10^{-8}	0	0.00002	1×10^{-7}	0	0.00009	5×10^{-7}	0	0.0005
Depleted UF_6 cylinders[d]											
Paducah	Truck	28,513	0.02	0	0.03	0.08	0	0.1	0.4	0	0.7
	Rail	7,129	0.01	0	0.005	0.02	0	0.02	0.06	0	0.1
Portsmouth	Truck	13,421	0.009	0	0.02	0.04	0	0.06	0.2	0	0.3
	Rail	3,356	0.005	0	0.003	0.008	0	0.01	0.03	0	0.05
Oak Ridge	Truck	4,732	0.003	0	0.006	0.01	0	0.02	0.06	0	0.1
	Rail	1,183	0.002	0	0.0009	0.003	0	0.004	0.01	0	0.02
UF_6 with overcontainers											
Paducah	Truck	28,351	0.01	0	0.03	0.04	0	0.1	0.2	0	0.7
	Rail	7,088	0.009	0	0.005	0.01	0	0.02	0.03	0	0.1
Portsmouth	Truck	13,388	0.005	0	0.02	0.02	0	0.06	0.09	0	0.3
	Rail	3,347	0.004	0	0.003	0.006	0	0.01	0.01	0	0.05
Oak Ridge	Truck	4,683	0.002	0	0.005	0.006	0	0.02	0.03	0	0.1
	Rail	1,171	0.001	0	0.0009	0.002	0	0.004	0.005	0	0.02

TABLE J.5 (Cont.)

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
U_3O_8 conversion facility											
Ammonia	Truck	0 – 520	NA	0	0 – 0.0006	NA	0	0 – 0.002	NA	0	0 – 0.01
LLW	Truck	320 – 1,420	0.00002 – 0.0001	0	0.0004 – 0.002	0.00009 – 0.0005	0	0.001 – 0.007	0.0005 – 0.003	0	0.007 – 0.03
LLMW	Truck	20	2×10^{-8}	0	0.00002	1×10^{-7}	0	0.00009	5×10^{-7}	0	0.0005
HF	Rail	0 – 4,860	NA	0	0 – 0.004	NA	0	0 – 0.01	NA	0	0 – 0.07
CaF_2	Truck	460 – 19,760	NA	0	0.0005 – 0.02	NA	0	0.002 – 0.09	NA	0	0.01 – 0.5
	Rail	180 –7,300	NA	0	0.0001 – 0.005	NA	0	0.0005 – 0.02	NA	0	0.003 – 0.01
UO_2 conversion facility											
Ammonia	Rail	960 – 1,120	NA	0	0.0007 – 0.0008	NA	0	0.003	NA	0	0.01 – 0.02
LLW	Truck	360 – 1,680	0.00007 – 0.0003	0	0.0004 – 0.002	0.0003 – 0.001	0	0.002 – 0.008	0.001 – 0.006	0	0.008 – 0.04
LLMW	Truck	20 – 40	2×10^{-8} – 5×10^{-8}	0	0.00002 – 0.00005	1×10^{-7} – 2×10^{-7}	0	0.00009 – 0.0002	5×10^{-7} – 1×10^{-6}	0	0.0005 – 0.0009
HF	Rail	0 – 4,860	NA	0	0 – 0.004	NA	0	0 – 0.01	NA	0	0 – 0.07
CaF_2	Truck	460 – 19,760	NA	0	0.0005 – 0.02	NA	0	0.002 – 0.09	NA	0	0.01 – 0.5
	Rail	180 –7,300	NA	0	0.0001 – 0.005	NA	0	0.0005 – 0.02	NA	0	0.003 – 0.01

TABLE J.5 (Cont.)

Facility/Material	Mode	Total Shipments[a]	Risks over 250 km: Radiological LCF[b]	Risks over 250 km: Chemical Effects[c]	Risks over 250 km: Vehicular LCF	Risks over 1,000 km: Radiological LCF[b]	Risks over 1,000 km: Chemical Effects[c]	Risks over 1,000 km: Vehicular LCF	Risks over 5,000 km: Radiological LCF[b]	Risks over 5,000 km: Chemical Effects[c]	Risks over 5,000 km: Vehicular LCF
Uranium metal conversion facility											
Ammonia	Rail	920	NA	0	0.0007	NA	0	0.003	NA	0	0.01
LLW	Truck	360 – 3,840	0.00003 – 0.004	0	0.0004 – 0.004	0.0001 – 0.02	0	0.002 – 0.02	0.0006 – 0.08	0	0.008 – 0.09
LLMW	Truck	20	2×10^{-8} – 7×10^{-8}	0	0.00002	1×10^{-7} – 3×10^{-7}	0	0.00009	5×10^{-7} – 1×10^{-6}	0	0.0005
HF	Rail	1,640	NA	0	0.001	NA	0	0.005	NA	0	0.02
MgF_2	Truck	10,320 – 10,780	NA	0	0.01	NA	0	0.05	NA	0	0.2 – 0.3
	Rail	3,800 – 3,980	NA	0	0.003	NA	0	0.01	NA	0	0.06
Cylinder treatment facility											
U_3O_8	Truck	22	0.00004	0	0.00003	0.0002	0	0.0001	0.0008	0	0.0005
LLW	Truck	88	3×10^{-7}	0	0.0001	1×10^{-6}	0	0.0004	5×10^{-6}	0	0.002
LLMW	Truck	20	4×10^{-9}	0	0.00002	2×10^{-8}	0	0.00009	8×10^{-8}	0	0.0005

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997). Exposure to ammonia was estimated to result in fatality for approximately 2% or less of those persons experiencing irreversible adverse effects.

[d] Includes the estimate for additional cylinders required to handle the depleted uranium in overfilled containers.

TABLE J.6 Total Accident Shipment Risks for the Transportation of Materials for the Cylinder Preparation and Conversion Options

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities
Cylinder transfer facility											
LLW	Truck	460 – 580	1×10^{-9} – 2×10^{-9}	0	0.004 – 0.006	5×10^{-9} – 6×10^{-9}	0	0.02	3×10^{-8}	0	0.1
LLMW	Truck	20	1×10^{-12}	0	0.0002	5×10^{-12}	0	0.0009	2×10^{-11}	0	0.004
Depleted UF_6 cylinders[d]											
Paducah	Truck	28,513	0.00008	5×10^{-6}	0.3	0.0003	0.00002	1	0.002	0.0001	6
	Rail	7,129	0.00001	2×10^{-7}	0.08	0.00004	7×10^{-7}	0.3	0.0002	4×10^{-6}	2
Portsmouth	Truck	13,421	0.00004	2×10^{-6}	0.1	0.0002	0.00001	0.5	0.0008	0.00005	3
	Rail	3,356	5×10^{-6}	8×10^{-8}	0.04	0.00002	3×10^{-7}	0.2	0.0001	2×10^{-6}	0.8
Oak Ridge	Truck	4,732	0.00001	8×10^{-7}	0.05	0.00005	3×10^{-6}	0.2	0.0003	0.00002	0.9
	Rail	1,183	2×10^{-6}	3×10^{-8}	0.01	7×10^{-6}	1×10^{-7}	0.06	0.00003	6×10^{-7}	0.3
UF_6 with overcontainers											
Paducah	Truck	28,351	0.00008	5×10^{-6}	0.3	0.0003	0.00002	1	0.002	0.0001	6
	Rail	7,088	0.00001	2×10^{-7}	0.08	0.00004	7×10^{-7}	0.3	0.0002	4×10^{-6}	2
Portsmouth	Truck	13,388	0.00004	2×10^{-6}	0.1	0.0002	0.00001	0.5	0.0008	0.00005	3
	Rail	3,347	5×10^{-6}	8×10^{-8}	0.04	0.00002	3×10^{-7}	0.2	0.0001	2×10^{-6}	0.8
Oak Ridge	Truck	4,683	0.00001	8×10^{-7}	0.05	0.00005	3×10^{-6}	0.2	0.0003	0.00002	0.9
	Rail	1,171	2×10^{-6}	3×10^{-8}	0.01	7×10^{-6}	1×10^{-7}	0.06	0.00003	6×10^{-7}	0.3

TABLE J.6 (Cont.)

Facility/Material	Mode	Total Shipments[a]	Risks over 250 km: Radiological LCF[b]	Risks over 250 km: Chemical Effects[c]	Risks over 250 km: Vehicular Fatalities	Risks over 1,000 km: Radiological LCF[b]	Risks over 1,000 km: Chemical Effects[c]	Risks over 1,000 km: Vehicular Fatalities	Risks over 5,000 km: Radiological LCF[b]	Risks over 5,000 km: Chemical Effects[c]	Risks over 5,000 km: Vehicular Fatalities
U_3O_8 conversion facility											
Ammonia	Truck	0 – 520	NA	0 – 0.1	0 – 0.005	NA	0 – 0.6	0 – 0.02	NA	0 – 3	0 – 0.1
LLW	Truck	320 – 1,420	2×10^{-7} – 7×10^{-7}	0	0.003 – 0.01	7×10^{-7} – 3×10^{-6}	0	0.01 – 0.06	3×10^{-6} – 0.00001	0	0.06 – 0.3
LLMW	Truck	20	7×10^{-11}	0	0.0002	3×10^{-10}	0	0.0008	1×10^{-9}	0	0.004
HF	Rail	0 – 4,860	NA	0 – 5	0 – 0.06	NA	0 – 20	0 – 0.2	NA	0 – 100	0 – 1
CaF_2	Truck	460 – 19,760	NA	0	0.005 – 0.2	NA	0	0.02 – 0.8	NA	0	0.09 – 4
	Rail	180 – 7,300	NA	0	0.002 – 0.09	NA	0	0.008 – 0.3	NA	0	0.04 – 2.0
UO_2 conversion facility											
Ammonia	Rail	960 – 1,120	NA	0.1	0.01	NA	0.5	0.05	NA	2 – 3	0.2 – 0.3
LLW	Truck	360 – 1,680	5×10^{-7} – 2×10^{-6}	0	0.004 – 0.02	2×10^{-6} – 8×10^{-6}	0	0.01 – 0.07	0.00001 – 0.00004	0	0.07 – 0.3
LLMW	Truck	20 – 40	7×10^{-11} – 3×10^{-10}	0	0.0002 – 0.0004	3×10^{-10} – 1×10^{-9}	0	0.0008 – 0.002	1×10^{-9} – 7×10^{-9}	0	0.004 – 0.008
HF	Rail	0 – 4,860	NA	0 – 5	0 – 0.06	NA	0 – 20	0 – 0.2	NA	0 – 100	0 – 1
CaF_2	Truck	460 – 19,760	NA	0	0.005 – 0.2	NA	0	0.02 – 0.8	NA	0	0.09 – 4
	Rail	180 – 7,300	NA	0	0.002 – 0.09	NA	0	0.008 – 0.3	NA	0	0.04 – 2.0

TABLE J.6 (Cont.)

Facility/Material	Mode	Total Shipments[a]	Risks over 250 km: Radiological LCF[b]	Risks over 250 km: Chemical Effects[c]	Risks over 250 km: Vehicular Fatalities	Risks over 1,000 km: Radiological LCF[b]	Risks over 1,000 km: Chemical Effects[c]	Risks over 1,000 km: Vehicular Fatalities	Risks over 5,000 km: Radiological LCF[b]	Risks over 5,000 km: Chemical Effects[c]	Risks over 5,000 km: Vehicular Fatalities
Uranium metal conversion facility											
Ammonia	Rail	920	NA	0.1	0.01	NA	0.4	0.04	NA	2	0.2
LLW	Truck	360 – 3,840	4×10^{-8} – 3×10^{-6}	0	0.004 – 0.04	1×10^{-7} – 0.00001	0	0.01 – 0.2	7×10^{-7} – 0.00006	0	0.07 – 0.8
LLMW	Truck	20	7×10^{-11}	0	0.0002	3×10^{-10}	0	0.0008	1×10^{-9}	0	0.004
HF	Rail	1,640	NA	2	0.02	NA	7	0.08	NA	30	0.4
MgF_2	Truck	10,320 – 10,780	NA	0	0.1	NA	0	0.4	NA	0	2
	Rail	3,800 – 3,980	NA	0	0.04 – 0.05	NA	0	0.2	NA	0	0.9
Cylinder treatment facility											
U_3O_8	Truck	22	1×10^{-6}	2×10^{-8}	0.0002	6×10^{-6}	7×10^{-8}	0.0009	0.00003	4×10^{-7}	0.004
LLW	Truck	88	7×10^{-10}	0	0.0009	3×10^{-9}	0	0.003	1×10^{-8}	0	0.02
LLMW	Truck	20	3×10^{-11}	0	0.0002	1×10^{-10}	0	0.0008	7×10^{-10}	0	0.004

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997). Exposure to ammonia was estimated to result in fatality for approximately 2% or less of those persons experiencing irreversible adverse effects.

[d] Includes the estimate for additional cylinders required to handle the depleted uranium in overfilled containers.

TABLE J.7 Consequences to the MEI from Routine Shipment of Depleted Uranium Materials

		Routine Radiological Risk from Single Shipment (Lifetime Risk of LCF[a])				
Facility/Material	Mode	Inspector	Resident	Person in Traffic	Person at Gas Station	Person near Rail Stop
Cylinder transfer facility						
LLW	Truck	2×10^{-9}	2×10^{-13}	6×10^{-9}	3×10^{-10}	NA
LLMW	Truck	9×10^{-11}	9×10^{-15}	3×10^{-10}	1×10^{-11}	NA
Depleted UF_6	Truck	3×10^{-8}	3×10^{-12}	1×10^{-7}	4×10^{-9}	NA
	Rail	6×10^{-8}	8×10^{-12}	1×10^{-7}	NA	5×10^{-10}
UF_6 with overcontainer	Truck	2×10^{-8}	1×10^{-12}	6×10^{-8}	2×10^{-9}	NA
	Rail	3×10^{-8}	3×10^{-12}	6×10^{-8}	NA	2×10^{-10}
U_3O_8 conversion facility						
LLW	Truck	2×10^{-9}	2×10^{-13}	6×10^{-9} – 8×10^{-9}	3×10^{-10}	NA
LLMW	Truck	9×10^{-11}	9×10^{-15}	3×10^{-10}	1×10^{-11}	NA
UO_2 conversion facility						
LLW	Truck	2×10^{-9} – 5×10^{-9}	2×10^{-13} – 5×10^{-13}	6×10^{-9} – 2×10^{-8}	3×10^{-10} – 7×10^{-10}	NA
LLMW	Truck	9×10^{-11}	9×10^{-15}	3×10^{-10}	1×10^{-11}	NA
Uranium metal conversion facility						
LLW	Truck	2×10^{-9} – 3×10^{-8}	2×10^{-13} – 3×10^{-12}	7×10^{-9} – 8×10^{-8}	3×10^{-10} – 4×10^{-9}	NA
LLMW	Truck	9×10^{-11}	9×10^{-15}	3×10^{-10}	1×10^{-11}	NA
Cylinder treatment facility						
U_3O_8	Truck	6×10^{-8}	5×10^{-12}	2×10^{-7}	7×10^{-9}	NA
LLW	Truck	8×10^{-11}	8×10^{-15}	2×10^{-10}	1×10^{-11}	NA
LLMW	Truck	1×10^{-11}	1×10^{-15}	5×10^{-11}	2×10^{-12}	NA
U_3O_8	Truck	6×10^{-8}	5×10^{-12}	2×10^{-7}	7×10^{-9}	NA
	Rail	7×10^{-8}	8×10^{-12}	2×10^{-7}	NA	5×10^{-10}
UO_2	Truck	5×10^{-8}	4×10^{-12}	2×10^{-7}	6×10^{-9}	NA
	Rail	6×10^{-8}	5×10^{-12}	2×10^{-7}	NA	3×10^{-10}
Uranium metal	Truck	1×10^{-8}	8×10^{-13} – 9×10^{-13}	3×10^{-8} – 4×10^{-8}	1×10^{-9}	NA
	Rail	1×10^{-8}	1×10^{-12}	3×10^{-8} – 4×10^{-8}	NA	7×10^{-11} – 8×10^{-11}
Uranium oxide casks						
LLW	Truck	1×10^{-8}	1×10^{-12}	3×10^{-8}	1×10^{-9}	NA
LLMW	Truck	1×10^{-9}	1×10^{-13}	4×10^{-9}	2×10^{-10}	NA
Cask	Rail	2×10^{-8}	2×10^{-12}	8×10^{-8}	NA	1×10^{-10}
Uranium metal casks						
LLW	Truck	2×10^{-9}	2×10^{-13}	5×10^{-9}	2×10^{-10}	NA
LLMW	Truck	5×10^{-9}	5×10^{-13}	1×10^{-8}	7×10^{-10}	NA
Cask	Rail	1×10^{-8}	1×10^{-12}	4×10^{-8}	NA	6×10^{-11}

[a] Lifetime risk of LCF for an individual was estimated from the calculated dose using the dose-to-risk conversion factor of 0.0005 fatalities per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the risk of LCF by 2,000 (i.e., 1 ÷ 0.0005).

TABLE J.8 Potential Radiological Consequences to the Population from Severe Accidents Involving Shipment of Materials for the Cylinder Preparation and Conversion Options

		Radiological Risk (LCF[a])					
		Neutral Weather Conditions			Stable Weather Conditions		
Facility/Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Cylinder transfer facility							
LLW	Truck	0.0002	0.0002	0.0004	0.0004	0.0004	0.0009
LLMW	Truck	4×10^{-6}	4×10^{-6}	8×10^{-6}	9×10^{-6}	9×10^{-6}	0.00002
Depleted UF_6	Truck	0.3	0.3	0.6	7	7	20
	Rail	1	1	3	30	30	60
U_3O_8 conversion facility							
LLW	Truck	0.0008 – 0.0009	0.0008 – 0.0009	0.002	0.002	0.002	0.004 – 0.005
LLMW	Truck	6×10^{-6}	5×10^{-6}	0.00001	0.00001	0.00001	0.00003
UO_2 conversion facility							
LLW	Truck	0.001 – 0.002	0.001 – 0.002	0.003 – 0.005	0.003 – 0.006	0.003 – 0.006	0.007 – 0.01
LLMW	Truck	0.00001 – 6×10^{-6}	0.00001 – 6×10^{-6}	0.00001 – 0.00003	0.00001 – 0.00003	0.00001 – 0.00003	0.00003 – 0.00007
Uranium metal conversion facility							
LLW	Truck	0.0005 – 0.002	0.0005 – 0.002	0.001 – 0.004	0.001 – 0.004	0.001 – 0.004	0.003 – 0.009
LLMW	Truck	6×10^{-6}	5×10^{-6}	0.00001	0.00001	0.00001	0.00003
Cylinder treatment facility							
U_3O_8	Truck	0.1	0.1	0.2	0.3	0.2	0.5
LLW	Truck	0.00001	0.00001	0.00003	0.00003	0.00003	0.00007
LLMW	Truck	3×10^{-6}	3×10^{-6}	6×10^{-6}	7×10^{-6}	6×10^{-6}	0.00001

[a] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

TABLE J.9 Potential Chemical Consequences to the Population from Severe Accidents Involving Shipment of Materials for the Cylinder Preparation and Conversion Options

		Number of Persons with Potential for Irreversible Adverse Effects[a]					
		Neutral Weather Conditions			Stable Weather Conditions		
Facility/Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Cylinder transfer facility							
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
Depleted UF_6	Truck	0	1	2	0	1	3
	Rail	0	1	3	0	2	4
U_3O_8 conversion facility							
Ammonia	Truck	0 – 1	0 – 100	0 – 200	0 – 10	0 – 1,000	0 – 3,000
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
HF	Rail	0 – 10	0 – 1,000	0 – 3,000	0 – 100	0 – 10,000	0 – 30,000
UO_2 conversion facility							
Ammonia	Rail	1	200	400	20	2,000	5,000
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
HF	Rail	0 – 10	0 – 1,000	0 – 3,000	0 – 100	0 – 10,000	0 – 30,000
Uranium metal conversion facility							
Ammonia	Rail	1	200	400	20	2,000	5,000
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
HF	Rail	10	1,000	3,000	100	10,000	30,000
Cylinder treatment facility							
U_3O_8	Truck	0	0	0	0	4	8
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0

[a] Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997). Exposure to ammonia was estimated to result in fatality for approximately 2% or less of those persons experiencing irreversible adverse effects.

TABLE J.10 Potential Consequences to the MEI from Severe Accidents Involving Shipment of Materials for the Cylinder Preparation and Conversion Options

		Accident Risk			
		Neutral Weather Conditions		Stable Weather Conditions	
Facility/Material	Mode	Radiological Risk of LCF[a]	Chemical Effects[b]	Radiological Risk of LCF[a]	Chemical Effects[b]
Cylinder transfer facility					
LLW	Truck	7×10^{-6}	No	0.0001	No
LLMW	Truck	2×10^{-7}	No	2×10^{-6}	No
Depleted UF_6	Truck	0.0002	Yes	0.0005	Yes
	Rail	0.0009	Yes	0.002	Yes
U_3O_8 conversion facility					
Ammonia	Truck	NA	Yes	NA	Yes
LLW	Truck	0.00003 – 0.00004	No	0.0006	No
LLMW	Truck	2×10^{-7}	No	4×10^{-6}	No
HF	Rail	NA	Yes	NA	Yes
UO_2 conversion facility					
Ammonia	Rail	NA	Yes	NA	Yes
LLW	Truck	0.00006 – 0.0001	No	0.0009 – 0.002	No
LLMW	Truck	$2 \times 10^{-7} – 6 \times 10^{-7}$	No	$4 \times 10^{-6} – 9 \times 10^{-6}$	No
HF	Rail	NA	Yes	NA	Yes
Uranium metal conversion facility					
Ammonia	Rail	NA	Yes	NA	Yes
LLW	Truck	0.00002 – 0.00007	No	0.0004 – 0.001	No
LLMW	Truck	2×10^{-7}	No	4×10^{-6}	No
HF	Rail	NA	Yes	NA	Yes
Cylinder treatment facility					
U_3O_8	Truck	0.004	Yes	0.07	Yes
LLW	Truck	6×10^{-7}	No	9×10^{-6}	No
LLMW	Truck	1×10^{-7}	No	2×10^{-6}	No

[a] Lifetime risk of LCF for an individual was estimated from the calculated doses using a dose-to-risk conversion factor of 5×10^{-4} fatality per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,000 (i.e., 1 ÷ 0.0005).

[b] Yes or No applies to the effect of chemical exposure on the MEI. There is no probability estimate; either there would or would not be an irreversible adverse effect. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997). Exposure to ammonia was estimated to result in fatality for approximately 2% or less of those persons experiencing irreversible adverse effects.

Transportation impacts associated with the cylinder transfer facility would be very small. No vehicle-related fatalities would be expected (< 1), and the vehicle-related risks would be about 10 times higher than the radiological risks. No radiological fatalities or irreversible adverse chemical effects would be expected as a result of a potential severe accident. The highest potential routine radiological exposure to an MEI, with a latent cancer fatality risk of 6×10^{-9}, would occur for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be about 100 times less than the exposure a person receives from natural sources in the course of 1 day.

J.3.4 Conversion Options

The conversion options would involve transportation of the depleted UF_6 cylinders from their current locations at the three storage sites to a conversion facility, transportation of any chemicals required by the conversion process, and transportation of the waste materials to a disposal site. Transportation of the conversion products is included in the discussion of the long-term storage, manufacture and use, and disposal options in Appendices G, H, and I of this PEIS.

The total collective radiological risks (i.e., the total risks to all workers and members of the public potentially exposed) associated with transportation of the depleted UF_6 cylinders; conversion to U_3O_8, UO_2, and metal; and the cylinder treatment facility are summarized in Tables J.5 and J.6 for routine and accident risks, respectively. Table J.7 summarizes the routine risks to MEIs, and Tables J.8 and J.9 summarize the potential severe accident consequences to local populations from radiological and chemical hazards, respectively. Table J.10 summarizes the accident consequences to MEIs.

J.3.4.1 Transportation of Depleted UF_6

The initial step in the conversion process would be to deliver the depleted UF_6 from the three storage sites to the conversion facility. The cylinders would be prepared for transport at each site, as discussed in Section J.3.3, and shipped to the conversion facility location. Shipment of all cylinders by both truck or rail has been assessed. Rail shipments would consist of four cylinders per railcar, whereas truck shipments would involve only one cylinder per truck. Because the number of cylinders that might require overcontainers is uncertain at this time, impacts were assessed for two bounding cases: under the first case, the depleted UF_6 would be transferred from nonconforming cylinders to new cylinders before transport; under the second case, all cylinders would be shipped in protective overcontainers. Risks for a given combination of cylinder shipments with and without overcontainers can be obtained by a linear interpolation between the two cases.

Protective overcontainers would reduce the external radiation emanating from the shipments by a factor of almost two. Because the radiological risk would be dominated by exposure during routine transport, the radiological risk from shipments with overcontainers would also be about half the value for shipments without overcontainers. On the other hand, shipment of the depleted UF_6 cylinders in overcontainers is not expected to provide additional protection under severe accident conditions. Therefore, the risks from shipment of cylinders with and without overcontainers would be expected to be the same for severe accidents.

The chemical risk associated with cylinder transport would be much less than the radiological risk; however, the total risks would be dominated by vehicle-related risks, which would be about 10 times larger than the radiological and chemical risks combined. Thus, risks from transport by rail appear to be slightly less than the truck risks because of higher shipment capacities and therefore fewer shipments.

Impacts from a potential severe accident could lead to fatalities from both radiological and chemical effects. Up to 60 potential latent cancer fatalities from radiological hazards are estimated for a rail accident occurring in an urban population zone under stable weather conditions. On the basis of chemical toxicity effects for the same conditions, up to 4 persons could be affected by irreversible adverse effects.

The highest potential routine radiological exposure to an MEI, with a latent cancer fatality risk of 1×10^{-7}, would be for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be approximately 5 times less than the exposure a person receives from natural sources in the course of 1 day.

J.3.4.2 Conversion to U_3O_8, UO_2, or Metal

Conversion of the depleted UF_6 to the U_3O_8 or UO_2 oxide forms was assessed for both long-term storage (Appendix G) and disposal (Appendix I); conversion to UO_2 or metal was also assessed for use in cask manufacture (Appendix H). Transportation of other materials related to the conversion process would include the ammonia used in the conversion processes and the LLW, LLMW, and HF by-products of the conversion processes.

The total transportation risks associated with the conversion process would be low for all three conversion processes. The LLW and LLMW shipments to disposal would pose no irreversible adverse chemical effects, and the radiological risks would be about 100 times less than the vehicle-related risks. The largest risks would be associated with the chemical hazards associated with transportation of the HF by-product. These risks would be about 100 times the vehicle-related risks.

No radiological fatalities would be expected as a result of a potential severe accident. A severe accident involving ammonia or HF could result in fatalities, with a potential for approximately 30,000 persons to experience irreversible adverse effects from an accident involving HF under stable conditions in an urban area. However, the overall probability of an anhydrous HF accident occurring would depend on the total number of shipments and the actual locations of the origin and destination sites. The probability of an accident would increase with the number of shipments and distance between sites. Approximately 5,000 railcars of anhydrous HF would be produced if the entire UF_6 inventory were converted to oxide. Assuming the distance traveled per shipment is 620 miles (1,000 km) and based on national average accident statistics for railcars, the overall probability for such an accident in an urban area would be about 3×10^{-5} (about 1 chance in 30,000) over the duration of the program. The resulting overall risk to the public (defined as the product of the accident consequence and the probability) would be 1 irreversible adverse effect (i.e, about 1 person would be expected to experience irreversible adverse effects) due to HF-related transportation accidents. This calculation assumes that the accident would occur in an urban area under weather conditions that result in maximum consequences. Further discussion on potential severe anhydrous HF accidents is presented in Chapter 5, Section 5.2.2.2.

The risk of latent cancer fatality to an MEI from a single routine radiological exposure to a given shipment would be negligible. The highest potential exposure, with an LCF risk of 6×10^{-9}, would occur for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be approximately 100 times less than the exposure a person receives from natural sources in the course of 1 day.

J.3.4.3 Cylinder Treatment Facility

After the depleted UF_6 cylinders were "emptied" at the conversion facility, they would still retain approximately 22 lb (10 kg) of UF_6, which corresponds to the amount remaining in the cylinder in the vapor phase at autoclave pressure and temperature (Charles et al. 1991). A cylinder treatment facility was assumed to be colocated with the conversion facility to clean and decontaminate the cylinders once they had been emptied. Therefore, the only chemical or radioactive material transportation risks would be from small amounts of U_3O_8, LLW, and LLMW generated at the facility. It was assumed that the cleaned cylinders would be placed in the scrap metal pile at the conversion site.

No fatalities would be expected due to transportation of materials from the cylinder treatment facility. The highest potential routine radiological exposure, with a latent cancer fatality risk of 2×10^{-7}, would occur for a person stopped in traffic near a shipment of U_3O_8 for 30 minutes at a distance of 3.3 ft (1 m) if it were shipped to a disposal site. Such an exposure would be less than half the radiological exposure that a person receives from natural sources in the course of 1 day.

Less than one radiological latent cancer fatality might be expected as a result of a potential severe accident involving shipment of U_3O_8 under stable weather conditions. Because of the chemical toxicity of the uranium oxide, approximately 8 persons could experience irreversible adverse effects in an urban area under stable weather conditions.

J.3.5 Long-Term Storage Options

Three options were assessed for long-term storage of depleted uranium compounds at a single location. The depleted uranium could be stored in its current form as depleted UF_6 or converted to an oxide form (UO_2 or U_3O_8) and then stored. Transportation impacts related to conversion of the depleted UF_6 to the oxide forms are discussed in Section J.3.4.2. Potential impacts from transportation of the depleted uranium material in its final form to a long-term storage site are discussed in this section.

Small amounts of waste could be generated due to container failure during the surveillance phase of the long-term storage options. The impacts of transporting this waste to a disposal site was not considered because the number of associated shipments would be less than one per year (LLNL 1997).

The estimated impacts associated with transportation for the long-term storage options are presented in Tables J.11 through J.14. The total collective radiological risks (i.e., the total risk to all workers and members of the public potentially exposed) are summarized in Tables J.11 and J.12 for routine and accident risks, respectively. Table J.7 summarizes the routine risks to MEIs, and Tables J.13 and J.14 summarize the potential severe accident consequences to local populations and MEIs, respectively.

J.3.5.1 Storage as Depleted UF_6

Long-term storage of depleted UF_6 at a single storage site would involve shipping the depleted UF_6 cylinders from their current locations at the three existing storage sites. The potential transportation impacts from shipping these depleted UF_6 cylinders to a storage facility would be the same as for shipping to a conversion facility (Section J.3.4.1).

J.3.5.2 Storage as U_3O_8 or UO_2

Long-term storage of depleted uranium as U_3O_8 or UO_2 would involve shipping the oxide from a single conversion facility to the storage site. The same impacts would also be incurred from shipping the oxide from a conversion facility or storage site to a disposal site (Section J.3.7) or to a cask manufacturing facility (Section J.3.6).

The radiological risk associated with shipping all of the U_3O_8 or UO_2 to a storage site from a conversion facility would be larger than the chemical risk, but the total risks would still be dominated by vehicle-related risks, which would be about 10 times larger than the radiological risks. Therefore, risks from rail transport would be less than risks from truck transport because of higher shipment capacities and therefore fewer shipments.

TABLE J.11 Total Routine Shipment Risks for the Transportation of Materials for Long-Term Storage

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
Depleted UF_6 cylinders[d]											
Paducah	Truck	28,513	0.02	0	0.03	0.08	0	0.1	0.4	0	0.7
	Rail	7,129	0.01	0	0.005	0.02	0	0.02	0.06	0	0.1
Portsmouth	Truck	13,421	0.009	0	0.02	0.04	0	0.06	0.2	0	0.3
	Rail	3,356	0.005	0	0.003	0.008	0	0.01	0.03	0	0.05
Oak Ridge	Truck	4,732	0.003	0	0.006	0.01	0	0.02	0.06	0	0.1
	Rail	1,183	0.002	0	0.0009	0.003	0	0.004	0.01	0	0.02
UF_6 with overcontainers											
Paducah	Truck	28,351	0.01	0	0.03	0.04	0	0.1	0.2	0	0.7
	Rail	7,088	0.009	0	0.005	0.01	0	0.02	0.03	0	0.1
Portsmouth	Truck	13,388	0.005	0	0.02	0.02	0	0.06	0.09	0	0.3
	Rail	3,347	0.004	0	0.003	0.006	0	0.01	0.01	0	0.05
Oak Ridge	Truck	4,683	0.002	0	0.005	0.006	0	0.02	0.03	0	0.1
	Rail	1,171	0.001	0	0.0009	0.002	0	0.004	0.005	0	0.02
U_3O_8	Truck	25,500	0.05	0	0.03	0.2	0	0.1	0.9	0	0.6
	Rail	8,960	0.02	0	0.007	0.03	0	0.03	0.09	0	0.1
UO_2	Truck	26,260 – 26,800	0.04	0	0.03	0.2	0	0.1	0.8	0	0.6
	Rail	8,480 – 8,800	0.01	0	0.006 – 0.007	0.02	0	0.03	0.06	0	0.1

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

[d] Includes the estimate for additional cylinders required to handle the depleted uranium in overfilled containers.

TABLE J.12 Total Accident Shipment Risks for the Transportation of Materials for Long-Term Storage

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Facility/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities
Depleted UF_6 cylinders[d]											
Paducah	Truck	28,513	0.00008	5×10^{-6}	0.3	0.0003	0.00002	1	0.002	0.0001	6
	Rail	7,129	0.00001	2×10^{-7}	0.08	0.00004	7×10^{-7}	0.3	0.0002	4×10^{-6}	2
Portsmouth	Truck	13,421	0.00004	2×10^{-6}	0.1	0.0002	0.00001	0.5	0.0008	0.00005	3
	Rail	3,356	5×10^{-6}	8×10^{-8}	0.04	0.00002	3×10^{-7}	0.2	0.0001	2×10^{-6}	0.8
Oak Ridge	Truck	4,732	0.00001	8×10^{-7}	0.05	0.00005	3×10^{-6}	0.2	0.0003	0.00002	0.9
	Rail	1,183	2×10^{-6}	3×10^{-8}	0.01	7×10^{-6}	1×10^{-7}	0.06	0.00003	6×10^{-7}	0.3
UF_6 with overcontainers											
Paducah	Truck	28,351	0.00008	5×10^{-6}	0.3	0.0003	0.00002	1	0.002	0.0001	6
	Rail	7,088	0.00001	2×10^{-7}	0.08	0.00004	7×10^{-7}	0.3	0.0002	4×10^{-6}	2
Portsmouth	Truck	13,388	0.00004	2×10^{-6}	0.1	0.0002	0.00001	0.5	0.0008	0.00005	3
	Rail	3,347	5×10^{-6}	8×10^{-8}	0.04	0.00002	3×10^{-7}	0.2	0.0001	2×10^{-6}	0.8
Oak Ridge	Truck	4,683	0.00001	8×10^{-7}	0.05	0.00005	3×10^{-6}	0.2	0.0003	0.00002	0.9
	Rail	1,171	2×10^{-6}	3×10^{-8}	0.01	7×10^{-6}	1×10^{-7}	0.06	0.00003	6×10^{-7}	0.3
U_3O_8	Truck	25,500	0.002	0.00002	0.3	0.006	0.00009	1	0.03	0.0004	5
	Rail	8,960	0.0004	0.00002	0.1	0.001	0.00007	0.4	0.007	0.0004	2
UO_2	Truck	26,260 – 26,800	0.002	0 – 5×10^{-6}	0.3	0.006	0 – 0.00002	1	0.03	0 – 0.0001	5
	Rail	8,480 – 8,800	0.0004	3×10^{-6} – 6×10^{-6}	0.1	0.001	0.00001 – 0.00003	0.4	0.007	0.00005 – 0.0001	2

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

[d] Includes the estimate for additional cylinders required to handle the depleted uranium in overfilled containers.

TABLE J.13 Potential Consequences to the Population from Severe Accidents Involving Shipment of Materials for Long-Term Storage

		Radiological Risk[a] (LCF)					
		Neutral Weather Conditions			Stable Weather Conditions		
Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Depleted UF_6	Truck	0.3	0.3	0.6	7	7	20
	Rail	1	1	3	30	30	60
U_3O_8	Truck	0.1	0.1	0.2	0.3	0.2	0.5
	Rail	0.3	0.3	0.6	0.7	0.7	2
UO_2	Truck	0.1	0.1	0.2	0.2	0.2	0.5
	Rail	0.3	0.3	0.6 – 0.7	0.7 – 0.8	0.7	2
		Chemical Risk[b] (no. of persons with potential for irreversible adverse effects)					
		Neutral Weather Conditions			Stable Weather Conditions		
Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Depleted UF_6	Truck	0	1	2	0	1	3
	Rail	0	1	3	0	2	4
U_3O_8	Truck	0	0	0	0	4	8
	Rail	0	1	1	0	10	20
UO_2	Truck	0	0	0	0	1	2
	Rail	0	0	0	0	3	8

[a] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[b] Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

TABLE J.14 Potential Consequences to the MEI from Severe Accidents Involving Shipment of Materials for Long-Term Storage

		Accident Risk			
		Neutral Weather Conditions		Stable Weather Conditions	
Material	Mode	Radiological Risk of LCF[a]	Chemical Effects[b]	Radiological Risk of LCF[a]	Chemical Effects[b]
Depleted UF_6	Truck	0.0002	Yes	0.0005	Yes
	Rail	0.0009	Yes	0.002	Yes
UF_6 with overcontainer	Truck	0.0002	Yes	0.0005	Yes
	Rail	0.0009	Yes	0.002	Yes
U_3O_8	Truck	0.004	No	0.07	Yes
	Rail	0.01	Yes	0.2	Yes
UO_2	Truck	0.004	No	0.06	Yes
	Rail	0.01	No	0.2	Yes

a Lifetime risk of LCF for an individual was estimated from the calculated doses using a dose-to-risk conversion factor of 5×10^{-4} fatality per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,000 (i.e., 1 ÷ 0.0005).

b Yes or No applies to the effect of chemical exposure on the MEI. There is no probability estimate; either there would or would not be an irreversible adverse effect. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

The risk of latent cancer fatality to an MEI for a single exposure to a given shipment would be small. The highest potential exposure, with a latent cancer fatality risk of 2×10^{-7}, would occur for a person stopped in traffic near a shipment for 30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be less than half the radiological exposure that a person receives from natural sources in the course of 1 day.

Impacts from a potential severe accident could lead to fatalities from both radiological and chemical effects. Approximately 2 potential latent cancer fatalities from radiological hazards are estimated for a rail accident occurring in an urban population zone under stable weather conditions. Because of the chemical hazard of uranium, an estimated 20 people could experience irreversible adverse effects from chemical toxicity under the same conditions.

J.3.6 Manufacture and Use Options

Two alternative uses of depleted uranium were assessed: manufacture of casks using concrete made with cement and UO_2 and manufacture of casks using uranium metal. Potential impacts would be incurred from transport of the feed material (UO_2 or uranium metal) from a conversion facility to the manufacturing plant, transport of the manufactured cask to an end user, and transport of the small amount of LLW and LLMW expected to be generated at the manufacturing facility to a disposal site. Because of the size of the manufactured casks, cask shipment was assumed to occur by rail only. The shipment risks would be approximately the same for both cask options.

The collective population risks associated with the two manufacture and use options are summarized in Tables J.15 and J.16 for routine and accident risks, respectively. The routine risks to MEIs are summarized in Table J.7, and the accident consequences to MEIs and the population are summarized in Tables J.17 and J.18, respectively.

J.3.6.1 Uranium Oxide Casks

The uranium oxide cask option would involve the use of depleted uranium in the form of high-density UO_2 for the manufacture of depleted uranium concrete for shielding in spent nuclear fuel storage casks. The transportation risks associated with transport of the UO_2 to the cask manufacturing facility would be the same as the risks associated with transport of the UO_2 to a storage site (see Section J.3.5.2). Shipment of the uranium oxide casks to an end user would result in approximately the same overall risks as the UO_2 shipments. No chemical risks would be anticipated for transportation of the fabricated casks, and no radiological fatalities would be expected under severe accident conditions.

J.3.6.2 Uranium Metal Casks

The uranium metal cask option would involve the conversion of depleted UF_6 to uranium metal that would then be fabricated into a cask. Transportation impacts were analyzed for shipment of the uranium metal from a conversion facility to a cask manufacturing facility and shipment of the fabricated cask to an end user. No chemical transportation risks would be expected for this option.

The total radiological risk associated with uranium metal transport would be about a factor of 30 or more less than the vehicle-related risks. Shipment risks for the cask would be about the same as for rail transport of the uranium metal feed material. Risks for the generated waste shipments would be negligible compared with the shipment of uranium metal and casks.

The risk of latent cancer fatality to an MEI for a single exposure to a given shipment would be small. The highest potential routine radiological exposure, with a latent cancer fatality risk of 4×10^{-8}, would occur for a person stopped in traffic near a uranium metal or cask shipment for

TABLE J.15 Total Routine Shipment Risks for the Transportation of Materials for Manufacture and Use

Use/Material	Mode	Total Shipments[a]	Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
			Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF	Radiological LCF[b]	Chemical Effects[c]	Vehicular LCF
Uranium oxide casks											
UO_2	Truck	26,260 – 26,800	0.04	0	0.03	0.2	0	0.1	0.8	0	0.6
	Rail	8,480 – 8,800	0.01	0	0.006 – 0.007	0.02	0	0.03	0.06	0	0.1
LLW	Truck	300	0.0001	0	0.0003	0.0004	0	0.001	0.002	0	0.006
LLMW	Truck	20	1×10^{-6}	0	0.00002	4×10^{-6}	0	0.00009	0.00002	0	0.0005
Cask	Rail	9,600	0.003	0	0.007	0.005	0	0.03	0.02	0	0.1
Uranium metal casks											
Uranium metal	Truck	20,840 – 21,500	0.006 – 0.007	0	0.02 – 0.03	0.03	0	0.1	0.1	0	0.5
	Rail	7,360 – 7,520	0.002	0	0.006	0.004	0	0.02	0.01	0	0.1
LLW	Truck	1,540	0.0001	0	0.002	0.0004	0	0.007	0.02	0	0.04
LLMW	Truck	20	4×10^{-6}	0	0.00002	0.00001	0	0.00009	0.00007	0	0.0005
Cask	Rail	9,060	0.0002	0	0.007	0.0004	0	0.03	0.001	0	0.1

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

TABLE J.16 Total Accident Shipment Risks for the Transportation of Materials for Manufacture and Use

			Risks over 250 km			Risks over 1,000 km			Risks over 5,000 km		
Use/Material	Mode	Total Shipments[a]	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities	Radiological LCF[b]	Chemical Effects[c]	Vehicular Fatalities
Uranium oxide casks											
UO_2	Truck	26,260 – 26,800	0.002	0 – 5×10^{-6}	0.3	0.006	0 – 0.00002	1	0.03	0 – 0.0001	5
	Rail	8,480 – 8,800	0.0004	3×10^{-6} – 6×10^{-6}	0.1	0.001	0.00001 – 0.00003	0.4	0.007	0.00005 – 0.0001	2
LLW	Truck	300	2×10^{-12}	0	0.003	8×10^{-12}	0	0.1	4×10^{-11}	0	0.06
LLMW	Truck	20	8×10^{-11}	0	0.0002	3×10^{-10}	0	0.0008	2×10^{-9}	0	0.004
Cask	Rail	9,600	4×10^{-9}	0	0.1	1×10^{-8}	0	0.5	7×10^{-8}	0	2
Uranium metal casks											
Uranium metal	Truck	20,840 – 21,500	4×10^{-10}	0	0.2	2×10^{-9}	0	0.8	8×10^{-9}	0	4
	Rail	7,360 – 7,520	9×10^{-11}	0	0.09	4×10^{-10}	0	0.3 – 0.4	2×10^{-9}	0	2
LLW	Truck	1,540	2×10^{-6}	0	0.02	8×10^{-6}	0	0.06	0.00004	0	0.3
LLMW	Truck	20	7×10^{-11}	0	0.0002	3×10^{-10}	0	0.0008	1×10^{-9}	0	0.004
Cask	Rail	9,060	1×10^{-10}	0	0.1	4×10^{-10}	0	0.4	2×10^{-9}	0	2

[a] Risks for rail transport were estimated on a railcar basis; therefore, the number of railcars was used for the total number of rail shipments.

[b] Radiological LCFs were estimated from the calculated doses using dose-to-risk conversion factors of 0.0005 and 0.0004 fatality per person-rem for members of the general public and occupational workers, respectively, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,500 (i.e., 1 ÷ 0.0004).

[c] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

TABLE J.17 Potential Consequences to the MEI from Severe Accidents Involving Shipment of Materials for Manufacture and Use

		Accident Risk			
		Neutral Weather Conditions		Stable Weather Conditions	
Use/Material	Mode	Radiological Risk of LCF[a]	Chemical Effects[b]	Radiological Risk of LCF[a]	Chemical Effects[b]
Uranium oxide casks					
UO_2	Truck	0.004	No	0.06	Yes
	Rail	0.01	No	0.2	Yes
LLW	Truck	2×10^{-6}	No	0.00003	No
LLMW	Truck	2×10^{-7}	No	4×10^{-6}	No
Cask	Rail	0.0004	No	0.006	No
Uranium metal casks					
Uranium metal	Truck	0.0001 – 0.0002	No	0.002	No
	Rail	0.0004	No	0.007	No
LLW	Truck	0.00008	No	0.001	No
LLMW	Truck	2×10^{-7}	No	4×10^{-6}	No
Cask	Rail	0.0004	No	0.006	No

[a] Lifetime risk of LCF for an individual was estimated from the calculated doses using a dose-to-risk conversion factor of 0.0005 fatality per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,000 (i.e., 1 ÷ 0.0005).

[b] Yes or No applies to the effect of chemical exposure on the MEI. There is no probability estimate; either there would or would not be an irreversible adverse effect. Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

30 minutes at a distance of 3.3 ft (1 m). Such an exposure would be approximately 10 times less than the exposure a person receives from natural sources in the course of 1 day.

No fatalities from severe accidents would be expected. The transportation risks associated with the transport of the uranium metal cask would be approximately the same as those for the uranium oxide cask.

J.3.7 Disposal Options

Two options were identified for potential disposal of the depleted uranium: disposal as U_3O_8 or disposal as UO_2. In each case, the uranium oxide form would be transported from a single site, either a conversion facility or a storage site, to a disposal site. The impacts associated with

TABLE J.18 Potential Consequences to the Population from Severe Accidents Involving Shipment of Materials for Manufacture and Use

		Radiological Risk[a] (LCF)					
		Neutral Weather Conditions			Stable Weather Conditions		
Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Uranium oxide casks							
UO_2	Truck	0.1	0.1	0.2	0.2	0.2	0.5
	Rail	0.3	0.3	0.6 – 0.7	0.7 – 0.8	0.7	2
LLW	Truck	1×10^{-8}	1×10^{-8}	3×10^{-8}	3×10^{-8}	2×10^{-8}	5×10^{-8}
LLMW	Truck	6×10^{-6}	6×10^{-6}	0.00001	0.00001	0.00001	0.00003
Cask	Rail	3×10^{-6}	3×10^{-6}	6×10^{-6}	7×10^{-6}	5×10^{-6}	0.00001
Uranium metal casks							
Uranium metal	Truck	1×10^{-6}	8×10^{-7} – 9×10^{-7}	2×10^{-6}	3×10^{-6}	2×10^{-6}	4×10^{-6} – 5×10^{-6}
	Rail	3×10^{-6} – 4×10^{-6}	2×10^{-6}	5×10^{-6}	8×10^{-6} – 9×10^{-6}	6×10^{-6}	0.00001
LLW	Truck	0.002	0.002	0.004	0.005	0.005	0.01
LLMW	Truck	6×10^{-6}	6×10^{-6}	0.00001	0.00001	0.00001	0.00003
Cask	Rail	3×10^{-6}	2×10^{-6}	5×10^{-6}	8×10^{-6}	5×10^{-6}	0.00001

		Chemical Risk[b] (no. of persons with potential for irreversible adverse effects)					
		Neutral Weather Conditions			Stable Weather Conditions		
Material	Mode	Rural	Suburban	Urban	Rural	Suburban	Urban
Uranium oxide casks							
UO_2	Truck	0	0	0	0	1	2
	Rail	0	0	0	0	3	8
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
Cask	Rail	0	0	0	0	0	0
Uranium metal casks							
Uranium metal	Truck	0	0	0	0	0	0
	Rail	0	0	0	0	0	0
LLW	Truck	0	0	0	0	0	0
LLMW	Truck	0	0	0	0	0	0
Cask	Rail	0	0	0	0	0	0

[a] Radiological LCFs were estimated from the calculated doses using a dose-to-risk conversion factor of 0.0005 fatality per person-rem for members of the general public, as recommended in ICRP Publication 60 (ICRP 1991). The approximate corresponding dose received for each radiological fatality risk listed in this table may be obtained by multiplying the fatality risk by 2,000 (i.e., 1 ÷ 0.0005).

[b] Exposure to HF or uranium compounds was estimated to result in fatality for approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

transport to a disposal site would be the same as those for transport to a storage site (see Section J.3.5.2). Comparison of the transportation impacts associated with the two disposal options shows no significant difference between the two.

J.3.8 Other Impacts Considered But Not Analyzed in Detail

Other impacts could potentially occur if the transportation options considered in this PEIS were implemented, including impacts to air quality, water quality, ecology, socioeconomics, cultural resources, visual environment (e.g., aesthetics), recreational resources, wetlands, noise levels, and environmental justice issues. These impacts, although considered, were not analyzed in detail for one or more of the following reasons:

- Consideration of the impacts would not contribute to differentiation among the alternatives and therefore would not affect the decisions to be made in the Record of Decision that will be issued following this PEIS.

- The impacts could not be determined at the programmatic level without consideration of specific routes between specific sites. Potential impacts would be more appropriately addressed in the second-tier *National Environmental Policy Act* (NEPA) documentation when specific sites are considered.

J.4 REFERENCES FOR APPENDIX J

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